AN INVESTIGATION INTO THE HORIZONTAL CONTINUOUS CASTING OF STEEL BY

LAKE ONTARIO STEEL COMPANY LIMITED AND

THE UNIVERSITY OF TORONTO

CANMET S.T.A.R.T. PROGRAM

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SUMMARY

The technical proposal for Horizontal Continuous Casting (H.C.C.)of steels as submitted July 19, 1985 has been carried out.

A market survey has defined a large area of potential growth for Lake Ontario Steel (Lasco) products to be in the Special Bar Quality (S.B.Q.) steels. The manufacture of these could be facilitated by the H.C.C. process.

A study of present H.C.C. operations in North America has revealed clear economic advantages. Among these is a lower structural cost of installation, whether for replacement of conventional equipment or a "green-field" site.

The feasibility of casting stainless steels and remelt stock has been demonstrated. Including the casting of aluminum-killed steels without the problems incurred on conventional casting. Advantages over conventional casting techniques for carbon steels at this time are theoretical. It is felt that existing technology for H.C.C. casting of carbon steels requires significant improvements. These improvements can only be achieved by further developmental work. Therefore, the attached report recommends continued development by Lasco in collaboration with the University of Toronto. The report also includes specific recommendations for continued laboratory work which is not available at the industrial level. This would be enhanced further by industrial trials at Lasco Steel. Equipment and personnel costs would require Federal assistance.

1. INTRODUCTION

An H.C.C. installation at Lasco could occupy several roles: the improvement of product quality; the increase of product mix; the replacement of the present conventional continuous casting equipment (commissioned *circa* 1964).

Improvement of Product Quality

H.C.C. has the ability, either demonstrated or potential, for improvement in product quality which is difficult or impossible to achieve on conventional casting equipment.

Foremost, the ability to be able to cast aluminium-killed steels to achieve maximal levels of "cleanliness". By "killed" it is meant that an element with a high affinity for oxygen is added to the molten steel to reduce the level of what may be considered "gaseous oxygen". The most common element

preferred is aluminium because, in addition to lowering oxygen levels, it sets-up the metallurgical prerequisites for grain refinement on heat-treatment. However, in combining with oxygen - a scavenging operation - the by-product is a solid material, viz., aluminum oxide or alumina. If not removed, these solids can be detrimental to quality. Thus, the addition is made prior to casting, whereby these solids can be removed by stirring and floatation to a level of up to 5.0% of the total volume initially present. But even this minute quantity, while ensuring a very clean steel, is sufficient to deter or prohibit castability on small-section, conventional casters. The mechanism being the deposition of alumina in the bore of the 13 to 18mm diameter sizes of pouring nozzles causing constriction of metal flow and premature stoppage. However, when compared to conventional nozzles the H.C.C. break-rings (these may be considered akin to conventional nozzles) are at least 10 fold greater in area, consequently any deposition is limited and castability is achieved.

In addition, it must be mentioned that recent developments have permitted the casting of aluminium-killed steels via injection of calcium after

aluminium addition. However, as part of the process, there is a reduction of sulphur levels to a degree which reduces machinability. This, may not be conducive to end product processing, and therefore unsuitable to the customer. If aluminium-killed steels could be cast without calcium-treatment there would be a cost savings and the sulphur levels could be more easily maintained. This is a further justification for H.C.C.

Given that aluminium-killed steels can be cast, whether calcium-treated or not, on both H.C.C.and conventional casters, these steels must be protected from the air during pouring. On a conventional caster this may be in the form of an inert-gas shroud or a refractory tube submerged beneath the level of the steel in the mold. The latter may also include a mold powder which forms a protective layer over the exposed meniscus in the mold. In the case of H.C.C., the coupling of the mold to the pouring box or tundish provides for protection from the air as an inherent part of the system. In addition, no mold powders would be required. The result would be cost savings and elimination of operating problems as occurs in the use of shrouds and mold powders.

Another aspect of product quality improvement would be the operational ease of installing E.M.S. (electro-magnetic stirring). This essentially consists of a mechanism which generates a moving magnetic field. Its proximity to the steel at various points along a solidifying strand of steel billet causes a stirring action on the metal which has not yet solidified in the core. This stirring action homogenizes the chemistry over the cross-section in addition to ensuring structural "soundness". On conventional casters, implementation of this mechanism is difficult because it, requires firstly, a supply of cooling water and, secondly, that it is physically protected from mechanical or thermal damage. Maintenance is also difficult to achieve because of access. On the H.C.C. equipment the installation is relatively simple: it has simplicity of layout and accessibility for maintenance. .

Lastly, with H.C.C. there is the improvement in quality by elimination of mechanical-stress cracking which, on conventional casters, is difficult to control. This particularly applies to some very crack-sensitive micro-alloyed or very high carbon grades of steel. As may be readily obvious, the H.C.C. cast billets do not

require bending from vertical to horizontal planes most commonly practiced on conventional casters. Thus, mechanical stresses of this type are not applied.

The Increase of Product Mix

The increase of product mix would be largely concomitant with aforementioned improvements in quality and will be categorized as such.

Improvement of Product Quality

The ability to cast aluminum-killed steel,(aluminium added prior to casting) would guarantee that small-section billet product could compete with, if not surpass cleanliness levels of steel produced by other techniques. This would allow small section H.C.C. billets to be competitive in an area of the market which previously excluded conventionally cast billets.

Another area of product mix increase would be the ability to assure consistency of the recovery of micro-alloys such as titanium and boron which require that they be added after the steel is killed with aluminium to maximize their effect. This would again

open the doors in competing with other processes by penetrating, for example, the boron steels' market. One which is projected to be an ever-increasing market.

Where machinability requirements demand nominal levels of sulphur, aluminium-killed steels would be possible without calcium-treatment (a significant cost additive) assuring again competitiveness with other casting modes.

The inherent shrouding of the steels from the oxygen in the air would be yet another plus factor for product mix expansion, largely because the customers are becoming more familiar with steel processing and in many cases demand shrouded product as a specification.

Electro-Magnetic Stirring

With the provision of E.M.S. ensuring uniformity of chemistry in the center section of the product, a greater product mix would be possible particularly in the low alloy, high carbon and resulphurized grades. During solidification the tendency is for the above mentioned alloys to become more and more concentrated as the center of the cast product is approached.

The customer must now use costly annealing processes on the rolled product to homogenize the chemical and physical characteristics, otherwise a significant variation in mechanical properties will result. Center segregation can be decreased by other casting parameters but only E.M.S. would reproducibly guarantee the level of quality which would ensure that it is competitive with any other modes of production which does not have this inherent problem potential.

In addition E.M.S. would also ensure transverse structural soundness which is limiting product mix at present because, on certain customer forging techniques, the core looseness surfaces and causes seam-types of defects. This is of particular concern on some of the resulphurized steel applications.

Ability to Cast Crack-Sensitive Grades

While most grades can be presently cast on conventional casters, this requires very careful control of all parameters. However, H.C.C. would simplify this, ensuring that all of these products would be consistently crack-free (particularly as sometimes these cracks are difficult to detect). Secondly, there

are the very high carbon grades (1.0 - 1.5% C) that are practically impossible to cast on conventional equipment. H.C.C. would enlarge product mix in this area.

To Replace Present Conventional Equipment

Certainly at this point in time, an H.C.C. installation would not be considered for a green-field site on the Lasco premises. The major reason being that furnace capacity (ultra-high power) is presently available and will be coupled to a ladle refining system (arc reheat) to be commissioned December 1985. Consequently the installation of an H.C.C. machine, coupled with this equipment would be the best utilization of equipment and capital available.

The installation of H.C.C. would largely depend on its proven ability to achieve the kinds of aforementioned quality in addition to the advantages in maintenance costs which are ever increasing on the conventional equipment which has been in service for 20 years. While our market survey was limited, this must only be

construed as an initial objective with respect to market penetration and expansion. If the quality levels could be improved through H.C.C., as related to crack sensitive grades, improvement in structure and elimination of segregation, then this tonnage could be immediately increased.

However, in addition to quality the caster must undoubtedly be able to cast at productivity rates akin to conventional casters so that lower value product could still achieve maximal profit margins. This product would be cast as "filler" material when orders of special quality steels might be incoming at reduced levels.

To view an H.C.C. installation as added casting capacity at Lasco would be incorrect, particularly as the present capacity is being underutilized. This, in fact, is the world-wide scenario because of an over-capacity of steel. Any modification or addition of equipment will be solely designed to cast specific product which will yield the highest return on investment.

The technical proposal submitted on July 19, 1984, and now completed, has investigated each of these areas as

market studies, literature searches, including a comprehensive report by CANMET.* In addition, North American plant visits were conducted. The details of these investigations are discussed in the body of the report.

The original proposal listed four main objectives.

-Market Survey

-Technical Feasibility

-Economic Feasibility

-Technical problems and Areas of Improvement.

The conclusions of the report will address each of these objectives. Based upon these conclusions, recommendations are included which suggest the future direction for development in the field of horizontal continuous casting.

*Ferrco engineering Ltd., Technical and Economical Assessment of Horizontal Continuous Casting of Steel for CANMET, Department of Energy, Mines and Resources, Ottawa, September, 1979.

2. MARKET SURVEY

Lasco has been a supplier of special bar quality (S.B.Q.) steels to the North American market for over 10 years. These are basically A.I.S.I.and A.S.T.M. grades whose quality standards are regulated by these bodies. Lasco has no interest in the more specialized qualities, e.g., stainless, tool steels, etc. Thus, when we talk about "high quality steels" this simply means steels guaranteed to meet industry governed specifications or as per special request from the customer. The customer is, however, increasing his demand for quality levels in excess of those generally accepted by the market-place in the past and certainly Lasco is working toward satisfying these demands to remain economically viable. Thirty-six direct sales contacts in Canada and the U.S.A. were contacted regarding a possible increase in S.B.Q. business. This yielded the following results.

No. of Contacts	Categories	Potential Market (short tons)
15	New Business Existing Customers	80,000
16	New Forging	96,000
4	Automotive	80,000
1	Cold Drawing	90,000
Total 36		346,000

Lasco's tonnage of S.B.Q. business per annum has been typically 10% of our product mix. In 1984 this was 46,000 tons and in 1985 it is anticipated to be 55,000 tons. The above potential market, however, is only a portion of the total over-all market available. That is, for the purposes of this study, only 36 out of the 64 independent forgers using S.B.Q. steel have been contacted.

The majority of the above tonnage is fine-grain, carbon and low alloy steels. These would certainly be compatible with H.C.C. when it can be confirmed that this kind of technology is operationally viable. However, to suggest that H.C.C. in itself will generate the quality required for the above-mentioned grades, would be incorrect. H.C.C. would certainly facilitate those qualities as manufactured in up-stream melting and refining systems, such as the ladle reheat system being installed at Lasco and to be commissioned in December of 1985. In which case, economic prudence will not allow for a "green-field" H.C.C.installation. Rather, the H.C.C.would be coupled to the melting/refining system in place.

3. TECHNICAL FEASIBILITY

Introduction

At Lasco, the possibility of installing a horizontal continuous casting (H.C.C.) machine would be largely determined by the need to replace the conventional casting equipment in No.1 Melt Shop - vintage 1964. The life of the equipment is approaching a point in time whereby major structural repairs might be required. With the installation of a ladle furnace facility - completion in December of 1985 - new demands will be required of the existing equipment. The present intent is to make only such repairs as might be absolutely necessary, at least cost, to merely extend the life of the equipment for two, perhaps three years. During this time, the requirements for equipment should become more precise with respect to what is available technologically. At the same time, Lasco intends to maintain as much direct involvement in H.C.C. as possible, so that if the decision weighs in favor of H.C.C. it can be done on the basis of a scientific depth of knowledge.

3.1 TECHNICAL PARAMETERS

Using the existing conventional casting equipment as a base for comparison and for Lasco's requirements, any H.C.C. equipment must be technically feasible, satisfying four key parameters.

(i) Productivity

Being capable of producing 5.0"x5.0" and 5.0"x7.0" section billets at equivalent or greater rates of machine through-put (tons per hour) as compared with the conventional equipment.

(ii) Sequence Casting

Being capable of sequencing casting i.e., placing one heat on top of another heat in succession without teeming stoppage for a minimum of five heats.. This is to maximize yield of cast product and to minimize tundish refractory costs as "cold board" energy-efficient linings. These do not permit reuse once the tundish is "run-dry" after ladle teeming stoppage.

(iii) Quality Product

Being capable of producing quality product, i.e. it would have to be equivalent or better than that being produced on conventional casters. In addition, it would have to be capable of casting product which is presently difficult or

impossible to cast on conventional casting, machines, especially those cast as small cross-section billets (less than 64 square inches).

(iv) Compatibility with Present Rolling Mill(s)

It must be compatible with present rolling mill equipment available at Lasco. We would have to be sure that the H.C.C. billets could be rolled with pass reduction sequences similar to that being used to roll conventionally cast billets.

3.2. PLANT VISITS

The need to visit H.C.C. installations was to familiarize ourselves with actual operating equipment and to determine on a direct observational basis whether or not the equipment observed was indeed coincident with Lasco's requirements. The terms of our mandate limited our visits to plants in North America. Out of four plants visited, only two were casting billet section sizes comparable to conventionally cast sections at Lasco. The companies visited and machine designs are as follows:

(1) Chaparral Steel, Midlothian, Texas

Designed by Steel Casting Engineering, Orange, California.

Casting 5.0"x7.0" rectangular billets

(ii) Steel Casting Engineering, Orange, California

Designed by the same.

Casting small welding wire shapes

iii) Armco Steel, Baltimore, Maryland

Designed by Technica-Guss F.R. Germany

Casting 4.5"x4.5" and 6.0x6.0"

Billets, predominantly stainless

(iv) Cannon-Muskegon, Muskegon, Michigan

Designed by Technica-Guss, F.R. Germany

Casting 3.0" diameter rounds for remelt stock, plain carbon through more esoteric product, e.g. cobalt-stellite etc.

3.3 Comparison and Capability

(i) Productivity

From the actual heats observed and from what was reported to us, we have determined that both the Chaparral (one-strand) and Armco (2-strand) machines, if projected as 3-strand machines, would be capable of productivity rates comparable to those on conventional machines at Lasco. Based upon our understanding of each machine, we infer that there is a possibility of a small increase in productivity rates. However, this cannot be

precisely valued at this time. The limiting factor is, of course, the solidification rate at the solid/liquid interface. This requires more development with respect to material and heat-transfer characteristics of the break-ring and copper tube plus, perhaps, a fine-tuning of the fluid flow of liquid metal.

(ii) Sequence Casting

While no sequence casting was actually observed, Armco reported that it typically sequences two heats per day. That greater numbers of sequences are not being performed is primarily a limitation in break-ring life. The bulk of the grades are incompatible with break-ring refractory of the present composition. New compositions are being developed, e.g., silicon carbide plus boron nitride.

At Chaparral, no sequencing has been performed to date. Out of 150 tons only 25 tons of each heat melted is being processed via H.C.C. The tundish is of 25 ton capacity. This is filled and the balance of the heat is subsequently removed to be

cast conventionally. Additional equipment will be installed to accommodate the possibility of sequence casting in the near future and any limitations will be determined.

A. Zalner, Technica-Guss representative U.S.A., claims that one of their machines in Europe is casting long sequences, but further detail was unavailable.

In both cases the tundish linings were pre-heated brick, thus we were unable to observe any cold-board tundish lining practices. Both companies indicated an interest in cold-board practice as a future development.

(iii) Quality

Billet surface quality free from any oxide or refractory materials was typical of all billets examined at both Chaparral and Armco. The steels were well deoxidized with aluminium and the products of deoxidation removed prior to molten metal entry into the mold.

It is well known that of primary concern are the

so-called "cold shuts" which are a consequence of the solid/liquid interface occurring in the mold. This is caused by the intermittent withdrawl of the billet being pulled away from the face of the break-ring. This periodic withdrawal forms a void on a cyclical basis. Molten metal fills this void and the cycle begins again. However, homogeneous fusion does not occur. This then forms what is considered to be a plane of weakness and which could emerge as open cracks during casting or as subsequent tears during rolling.

At Armco, based upon observation of many stainless steel billet surfaces, the cold shuts, albeit difficult to see, did not propagate cracking. In other words, all of the most recent heats cast and available for observation were crack-free. Rolled product as rod also had good surface, and no tears or other blemishes were observed.

At Chaparral, because of the various production priorities, (see 3 (ii) Sequence Casting), a constant tundish level is not maintained and the steel is cast at a very high superheat,

Subsequently, these conditions are thought to be contributors to the transverse cracking problem which was observed. Suffice it to say that, at present, reliable billet quality is in question. However, the fact that Armco's cast product is virtually "crack" free, suggests that with some further work, Chaparral will be able to achieve similar results.

Insofar as the ability to cast products which are presently difficult or impossible (specifically steels aluminium-killed in the ladle); it is possible with the H.C.C. process. It is well known that small billet cross-section (small-metering nozzle) casters cannot achieve this except through very careful calcium treatment to modify the oxides so that these do not deposit out on the tundish nozzles and impair or prevent teeming. In visited plants, aluminium-killed steels from 0.025 Al tot. to 3.0% Al tot. have been cast on a regular basis with no impairment to castability. Thus, we can only conclude that the ability to cast A.K. steels would lead to opening up an unlimited potential in market penetration and resolve some of the problems in quality

experienced by small-section, conventional casting machines.

(iv) Compatibility with Present Rolling Mill(s)

That H.C.C. product should be compatible with conventional product rolling mill reduction sequences is a question which needs resolution. It has been implied that H.C.C. product needs preferential treatment by making the first two rolling passes light enough to reorientate the direction of the cold shut, preventing crack propagation. Conventional rolling employs heavy initial passes without problems. While no product was observed being rolled, indications strongly suggest that this sort of rolling logic is indeed correct. G.F.M. Austria, a manufacturer of rolling equipment, has gone so far as to develop a forging-type mill specifically for H.C.C. product. A "green-field" installation would thus require a rolling mill retrofit which would raise the cost of the H.C.C. installation significantly.

3.4 DISCUSSION AND CONCLUSION

Although this study was limited to two plants with H.C.C. equipment comparable to the cast section of conventional equipment at Lasco, and must also be curtailed by the fact that these installations are relatively new, there is sufficient evidence to suggest that -

(i) H.C.C. is capable of productivity rates comparable to conventional casters

(ii) Some sequencing is evident but this would have to be investigated further, perhaps in Europe and Japan where sequencing of greater numbers of heats is reported to be in operation.

(iii) The use of cold-board tundish linings is not yet in practice, awaiting the capability of being able to sequence sufficient steel tonnages to permit economic viability.

(iv) Billet surface quality is certainly a plus factor, primarily as regards to the ability to cast aluminium-killed steels. The traditional method of casting aluminium-killed steels on small section conventional casters is to add aluminium wire, continuously fed into the mold. This

generates refractory oxide which deposits itself on the billet surface and is detrimental to quality. Aluminium added prior to the mold can be processed such that these refractory oxides are removed. This can even be enhanced with calcium whenever oxide and sulphide morphology change is required.

(v) The cold-shut as a plane of weakness appears resolvable, but our feeling is that a great deal of development in various areas is yet required to control this. Beyond what we have observed through our visits to plants in North America, development work is proceeding, but European claims of greater resolution of this problem would have to be verified.

(vi) The question of rolling technology is important, particularly with regards to capital outlay. This must be investigated further to ensure that we would have compatible rolling mill technology to accommodate H.C.C. billets.

4. ECONOMIC FEASIBILITY

As was discussed in the section of the report entitled Technical Feasibility, if a H.C.C. machine was to be installed at Lasco, this would be located in No. 1 Melt Shop. If the technical feasibility was satisfied, the primary justification for installing H.C.C. would be to replace the existing machines before major structural repair costs might be incurred. In addition, there could be also a need to modify the present equipment to be more compatible with the ladle-arc furnace installation to ensure that the quality which will be generated can be maintained during the casting process.

Such a need would be to provide for equipment which would enable Lasco to cast crack-sentive grades such as low-alloy, high carbon and boron steels. The conventional straight mold caster has a small bending radius and this imparts stresses which can cause cracking. A partial resolution would be to increase this radius, but this would essentially entail the building of a curved-mold machine. The alternative would, of course, be an H.C.C. machine which would

eliminate bending altogether and at less cost because of lower structural costs.

The structural maintenance costs on the H.C.C. machine would be lower also. In fact, it might be projected that, in the long haul, the service life of an H.C.C. caster would be at least double that of conventional equipment - enhancing its investment attractiveness even further. The nature of the cooling systems on H.C.C. casters, particularly those without the secondary water sprays, eliminate the moisture laden environment which causes structural corrosion.

In No.1 Melt Shop the building is already provided. Crane traverse is also provided and is logistically located to ensure an efficacious materials-handling system for ladle transport, tundishes etc. The only structural costs would be those for tundish/mold assembly support, the drive and cut-off units and run-out table. If located adjacent to No.2 Caster, it would be feasible to tie into the present discharge bed via bridging. The basic structure height required would be no more than about 8 ft. to the top of the tundish when in place on the caster. This low structure would facilitate maintenance and, from an

operational stance, provide a preferred "birds-eye" view over the whole casting operation.

Another aspect making H.C.C. installation an attractive casting technology are the purportedly low operating costs. Our findings in this area were very limited primarily because the ultimate operational parameters, in terms of optimal rates of productivity, from what we have observed, have not yet been established.

From what we can determine and from what operational costing has been published, there is much variation. Our calculations suggest a reduction of up to 40% to an increase of 100% . This is, of course, a comparison of H.C.C. against our own highly productive operation which includes such operating parameters as:

(a) Supervision

(b) Labour

(c) Refractories

(d) Mold tube

(e) Natural gas

(f) Supplies and outside services

(g) Maintenance

(h) Water and services

On the other hand, even if operating costs were slightly higher - what that number might be is unknown - we would certainly consider this as a trade-off against such value-added parameters as follows:

(i) The ability to be able to cast fine-grain, aluminium-killed steels without the need to calcium treat for castability.

(ii) The ability to be able to cast a wide variety of crack-sensitive grades - greater market penetration .

(iii) The reduction or elimination of ladle-furnace treatment costs for a majority of products.

(iv) The elimination of shrouding technology presently being used on conventional casters, viz, tundish to mold shrouding to prevent reoxidation.

While the justification for installing an H.C.C. machine, as thus far discussed, has been largely positive, there is another consideration which must be examined. There are persistent demands from the market-place with respect to concern over reduction ratios from cast to rolled product. This is to maximize the homogeneity of grain structure as related to mechanical properties. With conventional

small-section caster, product size is limited by reduction ratios. With the advent of electromagnetic stirring, this might expand the limits to some extent, but not to the extent of ensuring that a maximal size range of product can be marketed. In which case, while the H.C.C. operations visited were limited to small-section billets, can this be expanded to be able to cast bloom-sizes? Though there are reports of larger sections being cast, observation of such operations to confirm this was beyond the scope of our investigation.

There is also the question of H.C.C. billet product as this relates to rolling mill technology. Do the initial passes have to be light to reorientate the cold-shut structures? If this might be the case, how cost efficient would it be to roll this material in our present mill? Or as an alternative, what might be the possibility and cost of accomplishing this via reduction stands on the caster itself.

One last consideration is the cost effectiveness of in-line rolling. If a new rolling mill were built, this could be coupled directly to the caster.

However, in this scenario, additional capital expenditure would be required to the point where perhaps a "green-field" site for a new steelmaking/rolling operation would be preferable.

In summary, that an H.C.C. caster for Lasco's No.1 Melt Shop would be economically feasible can only be affirmed if the outstanding questions and further developmental work is resolved. To accomplish this, more time will be required to ensure that all possible alternatives and scenarios are determined.

5. TECHNICAL PROBLEMS AND AREAS OF POTENTIAL IMPROVEMENT

5.1 DEFINITION OF MAJOR AREAS IN HORIZONTAL CONTINUOUS CASTING WHERE SOLUTIONS WOULD IMPROVE EFFICIENCY

The following are seen as the major problems which have been encountered in the course of this study.

(i) Surface Finish of Cast Billets or Bars

The intermittent nature of the withdrawal techniques associated with horizontal continuous casting gave rise to surface defects or imperfections (classified as cold shuts) which can open during the initial rolling stages and result in poor surface quality on the final product.

The extent to which this happens appears to be dependent upon the alloy being cast, the casting conditions, mold and break-ring design and the withdrawal cycles of the bar or billet. Much work has been done in this field but more needs to be done before acceptable surfaces can be obtained on a routine basis.

The factors such as withdrawal cycles, metal pressures and temperature, break-ring configuration, mold materials and design are presently being investigated, but there are limitations in terms of equipment and cost which are inhibiting the quick solution to these problems.

(ii) The Break-ring Material and design

The main problems relating to surface finish center around the conditions at the break-ring on the entrance of the liquid steel into the mold.

Boron nitride is at the present time the material giving the best results. It is, however, expensive, and much more knowledge is required of its behavior in the mold environment before real longevity can be obtained.

Apart from thermal expansion and conductivity, more studies need to be carried out on its volatilization at temperatures in excess of 1500^{o}C and the influence of oxygen within the liquid metal on its "break-down".

Although the material can be machined very easily, the

achievement of very close tolerances in the fit between the break-ring and copper mold will need the development of more accurate machinery and inspection techniques than presently in use.

(iii) Mold Wear and Design

Mold wear can be attributed to both mechanical, thermal and chemical reactions. Work must be done with respect to determining these mechanisms more precisely. And either controlling these or developing material compositions which would improve mold life. This might also be accomplished to some extent with mold design in terms of geometry.

(iv) After Cooling

With horizontal casting, the weight of the cast structure brings the lower face into more intimate contact with the lower half of the mold, and hence heat is extracted more readily from this region than from the top. This effect is exaggerated by the general shrinkage contracting the top surface from the mold.

The present approach to this problem is to keep the water-cooled copper mold short so that only a thin

shell forms, and to maintain the cooling by the pressure from within the liquid metal pressing the shell onto the cooling surface of the copper mold.

An after cooler is introduced whereby the main solidification process is achieved. This consists of graphite plates coupled to water cooled panels. This structure is critical in terms of design since it must provide adequate heat extraction, and be able to withstand abrasion to maximize its life for operational viability. The present designs, although they can achieve the contact and wear aspects cannot overcome the effects of gravity within the solidifying system. Some form of stirring must be introduced to alleviate this effect . Thus, to accomplish this, forms of electromagnetic or other forms of stirring might be used. An additional benefit of stirring would be to maximize cross-sectional chemical homogeneity. To effect improved after cooling, various billet geometries might also be investigated.

(v) Tundish Design

The function of the tundish is to provide a reservoir of metal for the casting process and, as such, it forms a vital part of the process.

There are two approaches to tundish design. The first, that it should be comparatively small being fed from a ladle such that a constant head of metal can be maintained and temperature controlled by the temperature existing in the ladle. By small, one means four to five tons such that major failure of the process as a whole would not be disastrous. The second, that it should be large enough to provide a ferro-static head of metal sufficient to ensure that the walls of the solidifying billets are forced against the plates of the after cooler. These pressures have been found to be those associated with an eight foot head of liquid metal in one instance and 2-4 feet in another. The head of metal can also provide feeding pressure to maintain central soundness of the billet.

Some form of heating of the tundish might be necessary. Induction methods have been tried but these can be comparatively expensive and require additional

attention. The possibility of using plasma jets, AC or DC together with argon stirring, may provide an answer.

(vi) Overall Design

More study is needed to arrive at the optimum design for an economically viable installation.

Answers need to be obtained as to overall configuration. Would a multi-strand set-up be feasible in view of the possible changes that may be necessary in the mold and break-ring during casting?

Ease of access may indicate that a two strand design may provide the better solution with the melt shop supplying metal to a large tundish, individually heated, which will provide sufficient metal head.

Twin sets of withdrawal mechanisms will be required, and designs for the gating system, the mold, and after cooler such that there is ease of mold and break-ring replacement.

The configuration will determine the capital cost, and the answers to a number of the technical problems must

be found for design optimization to be successful.

5.2 DEVELOPMENT REQUIRED TO ESTABLISH TECHNICAL VIABILITY FOR HORIZONTAL CONTINUOUS CASTING OF STEEL AND ITS ALLOYS

(i) The As Cast Surface

1. Continue work to determine mechanism of failure or defect formation with present casting parameters.

2. Ascertain whether or not there are heat flow periodicity effects.

3. Ascertain whether or not high pressures affect the mechanism of heat flow periodicity by:
   a. laboratory work
   b. if possible by large scale trials

4. Determine the effect of mold shape (metal flow at sharp corners).

5. Effect of metal stirring or pulsations timed with withdrawal cycles.

6. Study thermal conditions in vicinity of break-ring.

7. Study effect of alloy composition on break-ring and mold wear.

(ii) The Break-Ring

1. Is boron nitride the best material? What other material would be suitable? Carry-out comparisons on lab scale initially.

2. Determine effect of oxygen content of steel on wear of boron type and all other materials.

3. Carry out volatilization experiments with boron nitride and other materials, and steel at various temperatures.

4. Determine effect of cooling temperatures and break-ring wear.

5. Determine effect of thermal expansion and fit between mold and break-ring.

6. Improve methods of break-ring manufacture and inspection. Use of computer controlled machines and electronic copying devices to match break-ring insert dimensions with mold.

7. Evolve better instrumentation for determination of break-ring temperatures.

(iii) Mold Design

1. Optimize the alloy best suited to horizontal casting.

2. What methods of plating and what alloys would improve mold wear at point of contact with liquid metal? Would electro-plated composite coatings help?

3. Reduce mold costs by:
   a) improved forging or construction methods
   b) controlled machining.

4. Improve cooling in area of break-ring

(iv) Tundish Design

1. Pressure head experiments using gas pressure in tundish to create liquid pressure in casting. Methods of sealing require study. Lab scale experiments.

2. Maintenance of constant temperatures at a few degrees above the melting point either by induction or plasma arc need further study.

3. Configuration of tundish to provide metal head and easy access to gate and mold.

4. Small-scale laboratory work to study thermal conditions in proximity to cold entrance.

6. Conclusions

The initial technical proposal listed four main objectives -

1) Market Survey
2) Technical Viability
3) Economic Viability
4) Technical Problems and Areas of Improvement

6.1 Market Survey

The market survey shows a significant tonnage of product available if quality levels can be achieved. However, the A.I.S.I. and A.S.T.M. grades in this product mix are being achieved for the most part on conventional casting equipment. There is no doubt that H.C.C. would facilitate the quality manufacture of these grades and also provide a more flexible manufacturing system. By this is meant that, for example,aluminium-killed steels could be successfully cast by-passing secondary refining systems and micro-alloy injections. Thus, processing of the steel would have alternate routes depending on customer requirements.

6.2 Technical Feasibility

This is of paramount concern and it is felt that, at this time, it would not be possible to install H.C.C. equipment at Lasco and produce billets of acceptable quality for the present rolling mill(s) in the desired grades.

6.3 Economic Feasibility

The fact that the H.C.C. process is not considered by us to be technically ready makes an economic appraisal difficult. However, our judgement is that it appears the process would be economically feasible if the technical problems could be overcome without significant cost increases.

There are certainly economic advantages of H.C.C. over other established casting practices. The one demonstrated advantage is significantly lower structural costs as compared with conventional casters. It is also anticipated that operating costs could be similar to or lower than those for grades of steel we are interested in producing, but this would have to be investigated further.

6.4 Technical Problems and Areas of Improvement

Certainly the technical problems as outlined pose an enormous challenge. Most of the improvements have been in an industrial operational mode. The Armco and Chaparral developments have established insight into the process and have stimulated interest on the materials supply side, notably refractories companies. However, it is our judgement that much more work must be done and that involving university expertise testing equipment and facilities, would take the developmental work a significant step further. For this reason Lasco wishes to collaborate this work with the University of Toronto. Particularly since the university has an expressed interest in this area and have personnel who already have a demonstrated background in this process

HORIZONTAL CONTINUOUS CASTING PLANTS VISITED

The Horizontal Continuous Casting Plants visited and people whom we met are are follows -

1. Chaparral Steel, Midlothian, Texas, U.S.A.
   (Date - February 27 - 28, 1985)
   People whom we met -

Robert Oigerman, Casting Supervisor in charge of the H.C.C. machine development

John Beaton, General Casting Supervisor

Peter Wright, Vice President, Quality Control

Derek Saxby, Senior Metallurgist, Steelmaking

Manfred Hassig, Vice President, Steel Casting Engineering Ltd., the designer and manufacturer of the Chaparral H.C.C. machine. Hassig was present on the day of our visit to provide us with whatever technical details we might be interested in .

2. Armco Steel (Specialty Division), Baltimore, Maryland, U.S.A.
   (Date - March 27, 1985

People met (Armco)

William Tobiason, Superintendent, Melting and Rolling

Robert Williams, General Supervisor, Steelmaking

Gerry Gelazela, Senior Metallurgist, Steelmaking

Marty Latona, Process Metallurgist, Steelmaking

Albert Zalner, Technica-Guss Representative of North America with an office in Baltimore, Maryland, U.S.A. Formerly Casting Supervisor at Armco and was instrumental in starting up the H.C.C. He was most helpful in providing insight into the start-up and operation of the Technica-Guss machine.

3. Cannon-Muskegon Corp. Muskegon, Michigan U.S.A.

(Date - March 28, 1985)

People whom we met

Donald Rockwell, Plant Superintendent

Albert Zalner, Technica-Guss representative accompanied us on our visit to this plant and again was most helpful in describing its operation.

4. Steel Casting Engineering Ltd., Orange California U.S.A.

(Date - February 17-29, 1985

People whom we met

Max Ahrens -	President
Manfred Haissig	Vice President
Ralph Kutner -	Vice President

5. Japanese plants visited by Lasco and Co-Steel personnel but not funded by this project -

N.K.K. Ogishima Works May, 15, 1984

Contacts:

K. Hagiwara	Managing Director
N. Fujiwara	G.M. Iron & Steel Engineering
Y. Ikegami	G.M. Engineering & Consulting
M. Kubo	Mgr. Engineering & consulting
I. Kaneko	Asst. G.M. to Fujiwara
N. Ida	G.M. Plant Design
S. Komori	Mgr. Steelmaking Tech (Keihin)

That we have visited the above mentioned installations, has provided concrete insight into the H.C.C.technology

and operation in addition to raising more questions and suggesting very specific areas of development required. The people whom we met were very courteous and provided information in great detail, some of which is proprietary and/or could jeopardize their competitiveness if revealed as public record. We therefore will not publish any personal reports where mutual confidence has been established. However,to generate some documentation of the H.C.C. equipment and operation at these plants, we have included the references below which these plants have themselves published.

1. M. Haissig "Start up of a Horizontal Continuous Casting Machine for the Production of 5"x7" Square Billets", Electric Furnace Proc. Vol.42, 1984 pp.275-288

2. C.W. Smith "Induction Melting/Refining Continuous Casting Ni, Co. and Fe Base Master Alloys", Elect. Fce Proc., Vol 42 1984 pp. 239-245

3. A. Zalner "Horizontal Continuous Casting of Stainless Steel at Armco's Baltimore Works" Iron and Steel Eng. Feb. 1985 pp.37-44

4. NKK Report "The Horizontal Continuous Casting Process for High Alloy Stainless Tubular Goods", S. Komori; E. Sunami: A. Honda. I and Sm, Jan. 1985 pp.20-26

CURRENT WORK (UNIVERSITY OF TORONTO + STEEL CASTINGS)

STEEL CASTING ENGINEERING LTD., CALIFORNIA

SUMMARY OF COLLABORATIVE WORK WITH UNIVERSITY OF TORONTO ON HORIZONTAL CASTING

Background

After some preliminary studies of the literature and the approach by Dr. Thomson of CANMET (Energy, Mines & Resources), it was decided to set up a casting shop at the University of Toronto especially to carry out research in the field of horizontal continuous casting.

The original equipment from Energy & Mines was installed at U of T in 1983 and, whilst waiting for the installation of a melting furnace capable of some 250 lbs. of steel, work was carried out for a graduate thesis using aluminium as the base metal. The furnace was obtained from the Ontario Government by way of a BILD grant.

After a resume of existing techniques, it was decided that Steel Castings Engineering Ltd. had the most up-to-date withdrawal systems which, because of its electronic control and recording capabilities, was eminently suited to research, the results of which could be immediately translated to practice.

Steel Castings Engineering Ltd., were agreeable to the concept of collaborative work and, at considerable expense, put their small industrial scale equipment at the university's disposal.

Present Work

The first collaborative paper has been published and a second is in preparation.

The first dealt with the horizontal casting parameters and the ability of the system to cast the low carbon boron steels. These steels would be difficult to produce economically by all conventional techniques but the work done demonstrated that they could be produced by H.C.C. These materials might have future application because of their good welding and forming

properties. The second paper is strictly related to the understanding of the withdrawal sequences, which can be very accurately controlled by the torque motor system and their relationship to the surface defects.

It should, however, be noted that this work, since it is being carried out on small diameter bars, can be continued in the university laboratory.

Steel Casting Engineering Ltd. have been helpful supplying molds and dies, and the majority of the laboratory equipment is now at hand for the complete installation.

Conclusions from Present Work

The small scale experiments do appear to show a relationship with large scale practice. Certain anomalies, however, are becoming apparent which are beginning to throw some light on the mechanics of the defect formation

The field has opened up a very useful area of research for both graduate and masters' theses and will also provide enough fundamental problems to satisfy post

graduate and doctoral work.

*Note: The small 1/2" experiments have limitations and better correlation with practice could be obtained by casting a 2"x2" billet. With the present melting capacity at the university this should give a length of billet of the order of 20 feet, sufficient for equilibrium conditions to be achieved.

POOR
QUALITY
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